ECONOMY AND ENVIRONMENT PROGRAM
FOR SOUTHEAST ASIA

Marginal Opportunity Cost Pricing for Wastewater Disposal: A Case Study of Wuxi,China

Fan Zhang

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ABSTRACT

This project estimated the marginal cost of wastewater collection, disposal, and treatments in Wuxi, a newly industrialized medium-sized city in China. Based on the figures derived the full economic cost price of water was estimated. A cost and benefit analysis of wastewater collection and treatment was also carried out.

The damage estimates of wastewater disposal were linked to the cost of providing wastewater treatment. Different technological options for wastewater treatments and their costs were analyzed. Various levels of water quality improvement corresponding to these technological options were considered. The marginal cost of wastewater disposal, collection, and treatment was estimated using the Average Incremental Cost (AIC) approach. AIC curves were developed to show the relationship between the efforts to remove certain pollutants and the costs involved.

The net benefits from wastewater disposal and treatment were positive. The absolute value of net benefit was not large enough, however, and it could become negative if the costs could not be effectively reduced.

The project also estimated the marginal opportunity cost price of household water. In practice, the price of household water included the wastewater disposal cost. The water price estimated in the study was much higher than the current water price. The paper discusses the policy issues related to wastewater pricing and proposes a wastewater collection and treatment charge system for households and companies. A phased schedule of proposed tariffs and levels of pollution charges are also presented. These results are expected to guide policymakers in setting up the price of water at newly industrialized medium-sized cities in China.

MARGINAL OPPORTUNITY COST PRICING FOR WASTEWATER DISPOSAL: A CASE STUDY OF WUXI, CHINA

Fan Zhang[1]

1.0 INTRODUCTION

1.1 Importance of the Study

Industrialization has given birth to a new environmental problem in both developed and developing countries -- wastewater collection, disposal, and treatment. Inappropriate wastewater disposal is one of the major sources of water pollution in urban areas. The cost of wastewater collection, disposal, and treatment is an important component of the full economic cost of water supply in urban areas. The correct calculation of its marginal cost is important in estimating the marginal cost of water supply. A review of the existing literature on marginal cost pricing for water showed that this area has not been fully examined and hence, further research is needed.

China is rapidly developing. While industrialization has provided several benefits to the country, it has also brought with it serious water pollution problems. The total volume of wastewater disposed in China's urban areas increases by an average annual rate of 6.6 percent. Most wastewater is drained directly into rivers without any treatment. The percentage of industrial wastewater in relation to the total wastewater has decreased, while the percentage of live wastewater has increased since the mid-1980s. Table 1.1 shows the current condition of wastewater disposal in urban areas in China.

Table 1.1 Wastewater disposal in urban areas in China.

	1980	1985	1993	1995
Total volume of urban wastewater (10 km^3/day)	5,345	6,173	9,743	10,007
Industrial wastewater (10 km^3/day)	3,617	4,307	6,013	5,904
Industrial wastewater / total wastewater (%)	68	70	62	59

Source: Wu (1992) and China Statistical Yearbook (1996).

Wuxi is located in Jiangsu, one of the most rapidly developing provinces of China and first place in terms of total volume of disposed wastewater (8,080 km^3/day) and industrial wastewater (5,798 km^3 /day) in 1993.

Wuxi was chosen as the study area because:

1. It is rapidly industrializing, hence, the history of industrialization and wastewater disposal can be studied.
2. It is in a rapidly developing area and there is a good representative of the industrialized cities in the eastern coast of China.
3. It has available detailed statistical data.

[1] I would like to thank Professor Jeremy Warford, David Glover and Herminia Francisco for their helpful comments. I would also like to thank Wenji Bi, Gang Peng, Zhengwu Jiang, Haochun Zhou, Benzhi Chen, Maojun Jiang, Xiuwei Zhou, and Liangan Wu.

1.2 Research Objective

The project aimed to estimate the full economic price of water for household use in Wuxi, China, emphasizing the cost of wastewater collection, disposal, and treatment and their environmental impacts.

The specific objectives were:

a. to assess the impact of wastewater disposal in terms of impaired ability of the lake to produce potable water;

b. to estimate the cost and benefit of the wastewater collection and treatment project;

c. to develop an approach to measure the opportunity cost for wastewater collection, disposal, and treatment; and

d. to estimate the marginal opportunity cost (MOC) price of water in a medium-sized newly industrialized city represented by Wuxi.

The project's expected results included the following:

- An overall review of the conditions of water pollution, including both potable water supply and wastewater disposal in China, in general, and in Wuxi, in particular.

- A detailed review of the Lucun Wastewater Treatment Program, the main wastewater treatment project in Wuxi, including comparisons of different technical options, the improvement of water quality due to the treatment program, and the costs of the different phases of the wastewater treatment project.

- Calculation of the marginal cost of wastewater disposal, collection, and treatment using the Average Incremental Cost (AIC) to show the relationship between the effort to remove certain pollutants and the cost of doing so.

- A cost-benefit analysis, which included costs and benefits to industries, fish farmers, and urban households. The analysis showed that the treatment program has positive net benefits, but the result is sensitive to the assumptions of some key factors.

- A review of the current water tariff and wastewater charge system as well as an estimate of the full economic cost of water. The estimated tariff was much higher than the current tariff.

- A design of a wastewater collection and treatment charge system, in which households, small factories, and large factories would be treated differently. A phased schedule of proposed tariffs and levels of pollution charges were presented, showing a gradual pricing reform.

1.3 Research Methodology

The research was carried out over an 18-month period, beginning in January 1997. The researcher carried out five field investigations at Wuxi for more than five weeks. During the investigation, the researcher visited the Wuxi City municipal government, Economic Committee of Wuxi City municipal government, Bureau of Municipal Engineering, Bureau of Environmental Protection, Bureau of Pricing Management, Lucun Wastewater Treatment Plant, and Zhongqiao Potable Waste Plant. The researcher also visited the State Planning Committee of the central government and Tsinghua University in Beijing.

The researcher discussed the wastewater cost and pricing with the officials and researchers of the above institutes. The discussions included the following:

- The major pollutants being dumped into the Wuxi waterways and the alternative abatement technologies for these pollutants.

- Potable water supply and use in Wuxi; the quality of source water of the potable water plant; and the treatment process for potable water.

- The costs of wastewater treatment done by different industries.

- The recent changes in pricing policy of wastewater and potable water.

The project applied the Marginal Opportunity Cost (MOC) pricing approach to estimate the supply functions for water. According to the MOC theory (Warford, 1994), given a fixed demand function, the full economic price paid by the resource user should be equal to MOC. Water resources are optimally allocated and the costs of water use are minimized only under MOC pricing.

The principle of MOC pricing outlines the three major components for the supply of a natural resource: (a) marginal production costs (MPC), (b) marginal user costs (MUC), and (c) marginal environmental costs (MEC). The socially optimal price should equal the sum of these components.

MPC is the direct cost paid by the resource users in the process of resource production. In the case of water pricing, it includes investment and operation costs of added diversion works as well as costs of survey, planning, and monitoring. MUC is the net loss to future generations that will use the resources. In the case of water pricing, it includes net losses of depleted water resources imposed on future generations. MEC is the cost imposed by the resource users on other users or society. In the case of wastewater, because it is difficult to estimate the direct environmental cost of wastewater disposal, researchers often use investment and operating costs of wastewater collection and treatment project as a proxy of the environmental cost of wastewater disposal (Warford et al., 1994). It includes added treatment cost for sewage, added protection cost for water sources and water quality, and added cost of the loss of water quality caused by over-utilization or pollution discharge.

Capital indivisibility is a common phenomenon in water supply systems. Water supply can only be increased in large increments, not in small, separate quantities. To solve this problem in calculating marginal cost price of water, the Average Incremental Cost (AIC) of water supply was used as a proxy of MOC and was calculated by dividing the discounted value of future water supply cost by the similarly discounted amount of additional water to be consumed.

This project calculated the MOC of water use and water price in Wuxi. The investment and operating cost of wastewater collection and treatment project, used as proxy of the environmental cost of life water consumption, were also estimated (see section 3.3).

2.0 WATER POLLUTION IN WUXI

2.1 General Situation in Wuxi

Wuxi, a medium-sized city in Jiangsu province, had a non-agricultural population of 1,080,000 in 1996. It is a newly industrialized city in eastern China, 128 km northwest of Shanghai. Wuxi is one of the most rapidly industrialized cities in China. It is located in the Yangtse River delta, 40 km south of the Yangtse River, and on the northern shores of Lake Tai. The city is laced with over 200 km of waterways. Lake Tai to the southwest of the city is a major recreational attraction. Table 2.1 shows the value of total industrial production in Wuxi.

Table 2.1. Value of industrial production in Wuxi (in millions of yuan, 1990[2]).

Year	Real Value of Total Industrial Products
1980	5,891
1985	10,969
1990	16,691
1995	40,372
1996	44,091

Source: Statistical Yearbook of Wuxi 1997, p. 130.

The rapid development of town and village enterprises in the rural areas around Wuxi has been another cause of serious water pollution in Wuxi.

2.2 Water Supply and Uses in Wuxi

The state-owned Wuxi Water Supply Company provided about 260 million m^3 of potable water to the Wuxi urban area in 1996 (Table 2.2). Industry used more than 50 percent of the water. Seventy-five percent of the input water of the water plant came from Lake Tai (inland Lake Tai); the rest came from the Xibei Canal and boreholes. In addition, industry takes 60 million m^3 of water annually from the canals. Agriculture and fish farms also draw water from the canals. Table 2.2 summarizes the conditions of potable water supply and use in Wuxi.

[2] 8.3 yuan equals 1 US Dollar.

Table 2.2. Potable water supply and use in Wuxi.

Item	Unit[3]	1991	1992	1993	1994	1995	1996
Number of water plants		5	6	6	6	6	6
Capacity of water plants	10,000 tonne/day	57.4	76	77.5	92.5	92.5	109.5
Length of network	km	1,311	1,334	1,440	1,518	1,559	1,624
Total annual supply	10,000 tonne	18,247	19,848	22,708	24,578	25,667	26,041
Production use	10,000 tonne	10,028	11,298	13,410	14,539	14,144	13,447
Life use	10,000 tonne	5,721	6,518	7,401	7,770	9,048	10,401
Population	10,000	93.7	94.4	95.5	96.1	107.5	108.8
Per capita day life water use	Liter	150.3	171.0	212.3	221.5	230.6	262.0
Percent of population using piped water	%	100	100	100	100	100	100

Source: Statistical Yearbook of Wuxi 1997, p.366.

Use of water for production decreased in 1996 because the macroeconomic situation was not good.

2.3 Wastewater Disposal

Using the life water used per capita per day and a collection ratio of 0.85, the life wastewater disposal was calculated (Table 2.3).

Sixty percent of the 322,739 tonne/day of industrial wastewater (mainly cooling water) did not need treatment before disposal to the river system. Of the remaining wastewater, industry treated 55 percent (71,002 tonne/day) and the other 45 percent (58,093 tonne/day) was treated by the central treatment system.

Table 2.3. Estimated life wastewater and industrial wastewater disposal in Wuxi.

Item	Unit	1991	1992	1993	1994	1995	1996
Life wastewater disposed	tonne/day	133,229	151,789	172,352	180,945	210,707	242,215
Industrial wastewater disposed	tonne/day	-	-	-	-	382,315	322,739

Source: Statistical Yearbook of Wuxi 1997, p.368.

Table 2.4 shows that a large portion of wastewater came from textile and raw chemical materials and chemical products industries. Some industries accounted for only a small percentage of wastewater treated such as special purpose equipment manufacturing (1.87 percent), whose wastewater was not seriously polluted, and plastic products (0.16 percent) and entertainment (0.77 percent) industry, wherein most factories were small-scale and not well equipped with wastewater treatment equipment. The restaurant sector had a low percentage (2.80 percent) of wastewater treated because its treatment equipment was not efficient.

[3] m^3 is used interchangeably with tonne in this document

Table 2.4. Wastewater disposal from different industries in Wuxi in 1995.

Industry	Total value of product (10,000 yuan)	Annual wastewater disposed (10,000 tonne)	% of the total industrial wastewater	% of the total waste-water in the industry treated	% of the treated water in the industry meeting standard[4]
Textile	615,411.4	1,946.24	13.95	49.81	82.40
Raw chemical materials and chemical products	93,223.2	1,767.21	12.66	62.04	76.58
Food	60,807.8	1,055.37	7.56	37.14	81.46
Ferrous metals processing	83,924	887.74	6.36	25.07	99.97
Electronic and telecommunications	455,530.5	604.02	4.33	68.37	98.99
Ordinary machinery manufacturing	166,848.7	552.90	3.96	10.04	100
Petroleum processing and coke products	28,928.2	513.69	3.68	45.36	91.40
Special purpose equipment manufacturing	286,488.6	399.18	2.86	1.87	97.01
Medical and pharmaceutical products	65,984	383.30	2.75	9.13	100
Plastic products	65,606.4	276.46	1.98	0.16	89.19
Hotel	23,213.1	205.31	1.47	28.80	78.76
Restaurant	74,214.4	78.40	0.56	14.37	2.80
Entertainment	17,737.7	69.41	0.50	0.77	100
Sub-total	2,037,918	8,739.23	62.63	36.14	85.12
Total in Wuxi		13,954.52		47.48	92.22

Source: Wuxi Environmental Protection Bureau 1997

Textile Industry

Fifteen of the 40 textile factories were the main source of disposed wastewater, accounting for 70 percent of the total wastewater disposed by the whole textile industry. In cotton spinning, bio-chemical oxygen demand (BOD) load accounted for 15 percent of the weight of the raw materials. In wool spinning, on the other hand, wastewater comes from washing (75%), dyeing (24%), and starching (1%).

Most of the factories treated their wastewater using the chemical and biological approaches. In 1995, the total wastewater disposed was 19.46 million tonnes, 49.81 percent of which was treated; 82.40 percent of the treated water met the standards.

Table 2.5 shows that most of the textile industry's wastewater came from cotton processing. The average chemical oxygen demand (COD) contained in total input water (into the treatment equipment) was 18.570 tonne per day. After the treatment, the COD contained in the output water was reduced to 4.470 tonne per day.

[4] This is the percentage of the treated water meeting the standard. Some of the treated water does not meet the standard, e.g. for ordinary machinery manufacturing, 10.04 percent of the total water is treated, and 100 percent of the treated water meets the standard. Therefore, 10.04*100=10.04% of the total water is treated and meets the standard.

Table 2.5. Performance of the wastewater treatment equipment used in major textile factories, Wuxi, 1990.

	Volume (m^3/d)	COD(t/d)	
		Input	Output
Wool	4,400	3.233	0.907
Cotton	26,050	15.337	3.563
Total	30,450	18.570	4.470

Chemical Industry

The total amount of wastewater disposed by the chemical industry in Wuxi in 1995 was 17.67 million tonnes, 62.04 percent of which was treated; 76.58 percent of the treated water met the standards. The major pollutants produced by the chemical industry in 1990 included 6,800 tonnes of COD, 13 tonnes of phenol, 3.7 kg of Hg, and 5 kg of Cd.

Ferrous Metals Processing Industry

The Bureau of Metallurgical Industry operated 10 enterprises, which had 20,000 employees in 1990.

The main pollution sources in this industry were the steel plants. In 1995, 8.88 million tonnes of industrial wastewater were disposed, of which only 25.07 percent were treated.

The major steel plant in Wuxi was Wuxi Steel Plant, which primarily produced carbon steel and alloy steel. Components of its wastewater are given in Table 2.6 Restructuring of the production process in the early 1990s reduced the amount of disposed wastewater.

In 1990, the waste disposed by industry into the canals included 2,300 tonnes of COD, 1,870 tonnes of SS, 3.8 tonnes of phenol, and 0.5 tonne of cyanides.

Table 2.6. Wastes disposed by Wuxi Steel Plant[5].

Item	1990	1995
Wastewater (million tonnes/year)	17.42	1.21
COD (tonne/year)	1110.15	91.68
SS (tonne/year)	1249.50	103.25
Oil (tonne/year)	123.03	10.47

Medical and Pharmaceutical Industry

The Bureau of Medical and Pharmaceutical operated eight enterprises. Ninety percent of the enterprises' wastes came from various fermented products, including antibiotics. Wuxi had three major antibiotic factories.

[5] These are data from one major plant, Wuxi Steel Plant, not the whole industry.

Pharmaceutical Factory No.1. The major products were various natural and synthetic antibiotics. The factory has a very effective COD treatment equipment, such that the wastewater COD density was 300 mg/l, which was better than the designed density of 500 mg/l.

Pharmaceutical Factory No.2. The major products were fermented products. In 1990, it disposed of 2.37 million tonnes wastewater, of which only 2 percent met the environmental standard; only 5 percent were treated. A wastewater treatment plant was built in 1989, designed to have a COD removal rate of 85 percent; however, the actual COD removed was less than 80 percent.

The total wastewater volume of all industries in year 2000 was estimated on the basis of the industrial output. If the annual output reaches 60 billion yuan (US$ 7.22 billion), the total wastewater disposed of will be 200 million tonnes (45 percent residential wastewater and 55 percent industrial wastewater).

The cost of wastewater treatment of all industries in Wuxi ranged from $0.035 to $0.09 per tonne.

2.4 Water Quality and Water Pollution

Water quality has many attributes and there are correspondingly various measures of water quality. The reduction in water quality, population growth, and industrial production is highly correlated.

The waterways in Wuxi consist of the rivers around Wuxi and Lake Tai. The quality of the water in the rivers around Wuxi is influenced by the following factors: 1) increase in population and industrial activities in Wuxi; 2) economic development in the upper reaches of these rivers; and 3) increase in the volume of traffic on these rivers.

The water quality in the rivers around Wuxi has been reduced in the past 30 years. Wastewater has been a major cause of water pollution. In the 1960s, the city canals were suitable for swimming, washing, and fishing. Today much of its water is septic and malodorous. Wuxi had no sewerage system before the 1950s; hence, wastewater was directly disposed of into rivers. The first piped water plant was built in 1954. Some factories installed wastewater treatment equipment in the 1970s. The first wastewater treatment plant for residential areas was built in 1981. In 1983, the treatment ratio was 46 percent for industrial wastewater and 4.6 percent for residential wastewater. Industry contributed 75 percent of all wastewater discharged to the waterways in the 1980s. In the 1980s, the bad odor coming from major canals and other rivers was observed for a longer period, 30-60 days. The rivers around Wuxi contained NH_4-N, COD, and BOD, which were Chinese GB standard class 4 (i.e., seriously polluted).

Lake Tai is a shallow lake with an average depth of 2 meters. Its main pollution sources were:

- Life wastewater from the cities around the lake.
- Run-off from fertilizers and pesticides used by farmers near the lake.
- Industrial wastewater from factories around the lake.
- Animal disposals.
- Wastewater from hotels and hospitals around the lake.
- Wastes disposed by ships and boats passing by the lake.

On the average, the water quality in Lake Tai in the early 1990s was GB class 3. Inner Lake Tai, a small lake that is part of Lake Tai close to Wuxi City, was more polluted than the other parts of the lake.

Likewise, the water in Wuxi waterways was heavily polluted. Table 2.7 shows the water quality in Wuxi waterways.

Table 2.7. Water quality in Wuxi waterways.

Element	1990 mg/l	1995 mg/l	GB8978-88 standards Class 4	Main Problems
DO	1.68	5.5	>3.0	Foul odor; fish kill
BOD	10.15	6.5	<6.0	Health effects ; fish kill
NH_4-N	5.45	7.52	<2.0	Health effects
COD	30-50	7.3	0	Health effects; fish kill
SS b	10.00	71.2	<7.5	Aesthetic impact
Oil	1.34	1.06	<0.5	Health effects; fish kill; crop losses
Phenol	0.07	0.24	<0.01	Health effects; fish kill; crop losses
CN	0.02 a	0.018	0.2	Health effects; fish; crop losses
AS	0.01 a	0.008	0.1	Health effects; fish kill; crop loss

Source: Wuxi Environmental Protection Bureau (WEPB).
a. 1989 figures. b. The SS (suspended substance) standards shown here are indicative, not WEPB standards. That means if SS>7.5, it is aesthetically not acceptable.

The GB8978-88 Wastewater Disposal Standard was approved by the National Environmental Protection Bureau in January 1989. The standard describes the allowable density of disposed water.

Water conforming to GB8978-88 standard Class 4 is considered suitable for industrial use and boating. In 1990, the DO level was below 2 mg/l, the level desirable for aesthetic use in crowded residential areas. The COD, BOD, NH4-N, oil, and phenol levels were well above their standards, which meant that the water quality was not acceptable.

A research in 1987 (Hawksley 1993) showed that large volumes of pollutants were disposed of in Lake Tai and are taken from it for various uses (Table 2.8).

Table 2.8. Estimate of the pollutant load balance in Lake Tai.

Item	Pollutant Load (tonne / year)		
	Entering the lake	Removed from the lake	Remainder
COD	189,090	175,709	13,381
BOD	32,074	20,056	12,018
TN	28,106	25,001	3,105
TP	2,007	1,043	964
NO2-N	4,429	4,365	64
NO3-N	445	510	(65)
NO4-N	7,448	5,047	2,401

Source: Hawksley 1993.

Pollutants entered the lake in several ways: from rivers, waste disposal pipelines, and underground seepage. The pollutants were removed from the lake via water outflow, water plant's water intake, and underground leaching.

The water quality was worse near waste disposal points in the lower reaches of Wuxi (Table 2.9).

Table 2.9. Water quality in Inner Lake Tai and lower reaches of Lucun in 1995.

	Inner Lake Tai	Lower Reaches of Lucun
DO	8.1	1.2
BOD	6.0	7
COD	6.3	8.5
NH_3-N	-	-
SS	50.0	61.3
Oil	-	1.07
Phenol	0.004	0.066
CN	0.002	0.016
AS	0.003	0.011

Source: Wuxi Environmental Protection Research Institute.

3.0 MARGINAL OPPORTUNITY COST

The project used the MOC method to estimate the full economic price of water in Wuxi. The emphasis was on the calculation of the marginal cost of wastewater collection, disposal, and treatment. The impact of wastewater disposal was measured mainly in terms of the impaired ability of the lake to produce potable water because of wastewater disposal.

This project calculated the MOC of water use and water price in Wuxi. The estimated investment cost and operating cost of wastewater collection and treatment project, used as proxy of the environmental cost of life water consumption, are shown in section 3.3.

3.1 Marginal Cost of Wastewater Collection, Disposal, and Treatment

As mentioned elsewhere, the emphasis of this project was the MOC analysis for wastewater collection, disposal, and treatment. The marginal cost for wastewater collection, disposal, and treatment was included in the Marginal Environmental Cost (MEC). According to Warford (1994), marginal environmental costs can be divided into MEC1 and MEC2. The former arises at the production stage, while the latter arises at the consumption stage. Discharge of wastewater was included in MEC2, which created negative externalities.

Because it was difficult to estimate the direct environmental cost of wastewater disposal, investment and operating costs of wastewater collection and treatment projects were used as proxy of the environmental cost of wastewater disposal. The damage estimates were linked to the cost of providing wastewater treatment. The simplified water supply and wastewater disposal situation is shown in Figure 3.1. The water plants obtained most of their water input from Lake Tai. They provided potable water to the households and industry users. The wastewater was then disposed of, with or without treatment, into Lake Tai by the households and industry users.

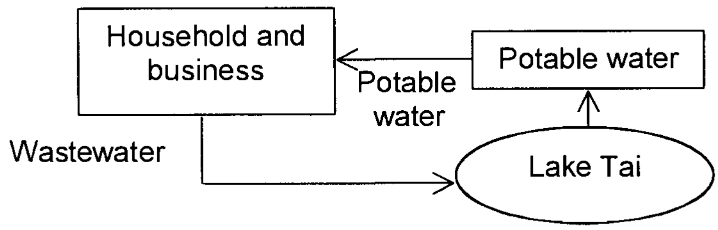

Figure 3.1 Water supply and wastewater disposal in Wuxi.

3.2 Technological Options for Wastewater Treatment

Sewerage and Treatment Program

This wastewater program had two components: sewerage and treatment. The sewerage system collected wastewater from all households and small- and medium-factories in the Lucun catchment area and transported these to the Lucun Sewage Treatment Works (LSTW). The Lucun catchment included the south, center, and northeast areas of the city and was estimated to account for more than 60 percent of wastewater from households and small factories in Wuxi. The program was divided into three treatment phases: the first phase had a daily capacity of 100,000 cubic meters of primary treatment and 50,000 cubic meters of secondary treatment (Table 3.1), the second phase increased the daily capacity to 200,000 cubic meters of primary treatment and 100,000 cubic meters of secondary treatment (Table 3.2). The third phase increased the daily capacity to 200,000 cubic meters of secondary treatment and 200,000 cubic meters of nutrient elimination (Table 3.3).

Table 3.1. Treatment capacities in Phase I of the program.

Item	Capacity
A. Sewerage	
Trunk sewers	37 km
Pumping stations	7
Reticulation sewers	23 km
B. Treatment Plant	
Primary treatment	100,000 tonne/day
Secondary treatment	50,000 tonne/day

Source: Wuxi Environmental Protection Bureau.

Table 3.2. Treatment capacities of Phase II of the program.

Item	Capacity
A. Sewerage	
Trunk sewers	44 km
Pumping stations	14
Reticulation sewers	205 km
B. Treatment Plant	
Primary treatment	Increased to 200,000 tonne/day
Secondary treatment	Increased to 100,000 tonne/day
C. Aeration devices	39

Source: Wuxi Environmental Protection Bureau.

Table 3.3. Summary of the treatment capacities of the Lucun Wastewater Treatment Plant.

	Capacity (m^3/day)			
Phase	Primary	Secondary	Nutrient elimination	Year
I	100,000	50,000		1987-1992
II	200,000	100,000		1993-1997
III	200,000	200,000	200,000	2000-

Source: Wuxi Environmental Protection Bureau.

Table 3.4. Features of the three main options for wastewater disposal.

Option	Before 2000	After 2000
1	Finishing Lucun sewerage and treatment plant, treated wastewater pumped to new canal. Northern sewerage and treatment plant built, treated wastewater pumped to old canal.[6]	Northern treatment plant pumps treated wastewater to new canal.
2	Lucun sewerage, and treatment plant completed, treated wastewater pumped to new canal. Northern sewerage and treatment plant built, treated wastewater pumped to old canal	Northern treatment plant pumps treated wastewater to Yangtse River.
3A	Lucun sewerage and treatment plant completed, treated wastewater pumped to new canal. Northern sewerage and treatment plant built, treated wastewater pumped to old canal	Northern treatment plant pumps treated wastewater to Yangtse River. Lucun treatment plant pumps treated wastewater to Yangtse River. Type of treatment in both plants: primary treatment.
3B	Lucun sewerage and treatment plant completed, treated wastewater pumped to new canal. Northern sewerage and treatment plant built, treated wastewater pumped to old canal	Northern treatment plant pumps treated wastewater to Yangtse River. Lucun treatment plant pumps treated wastewater treated to Yangtse River. Type of treatment in both plants: secondary treatment

Disposal Options

The Wuxi wastewater program considered three out of 18 options for wastewater disposal. These were (1) pumping all wastewater treated to the rivers around Wuxi; (2) pumping all wastewater to Yangtse River, which is more than 50 km from Wuxi; and (3) pumping part of the wastewater to the rivers around Wuxi and the rest to Yangtse River (Table 3.4). Their features are compared in Table 3.5.

[6] Both new and old canals are connected to Lake Tai.

Table 3.5. Comparison of the three alternative wastewater disposal options/projects.

Criterion	Project 1	Project 2	Project 3A	Project 3B
Long-term canal water quality	Can reach the target water quality.	Can reach the target water quality, better than Project 1.	Can reach the target water quality; best option.	
Long-term lake water quality	Can protect water quality to a certain degree.	Better than Project 1.	Best option.	
Long-term water quality in the Yangtse River	No effect.	Has effect.		
Flexibility	All projects have flexible transfer capacity between south and north parts of the city.			
Time	Whole project can be carried out quickly.	Most parts of the project can be carried out quickly.		
Reliability	Reliable	North part depends on the life of the pipes and the reliability of pumps; south part is reliable.	Depends on the life of the pipes and the reliability of pumps.	
Consequence of failure	Small	If pipes are broken, water quality will seriously deteriorate.	If pipes are broken, water quality will seriously deteriorate.	If pipes are broken, water quality will deteriorate.
Investment cost	Middle	High	Very high	Very high
Operating cost	High	High	Very high	Very high
Uncertainty	No	Technique and cost of trunk pipe.	Cost of double pipes.	Technique and cost of trunk pipe.
Evaluation	Easy to implement; local water quality worse than other projects but still meets the standards.	South part is easy to implement; north part has technical and administrative uncertainty. Better water quality than project 1.	Technical and administrative problems; expensive.	

After considering the above alternatives, the administration chose project 1, which meant treating wastewater in Wuxi and disposing treated wastewater to the rivers around Wuxi and then to Lake Tai. The following discussion focuses on Project 1.

Water Quality Improvement from Wastewater Treatment

The Wuxi Environmental Protection Bureau (WEPB) estimated that water quality standards will decline by one class by year 2000 if there will be no new wastewater treatment project. On the other hand, the wastewater treatment project will improve water quality by one class in 2000 when compared to the 1992 standards. Table 3.6 gives the current and estimated standards for the Grand Canal and Lake Tai.

Table 3.6. Current and projected water quality in the Grand Canal and Lake Tai.

	No Project		With Project
Location	1992	2000	2000
Grand Canal	5	5	4
Lake Tai	3	4	2

Source: WEPB. Using Chinese standard GB 3838-88.

Hawksley (1993) developed a water quality model for Wuxi, which included modeling attributes and causes of water quality. The causal factors included effluents from outside Wuxi, industrial effluent policies in Wuxi, the direction and strength of water flow to and from the Grand Canal, and water temperature.

Table 3.7. Alternative treatment technologies and level of pollutants (mg/l).

	Input water	Phase I[7]	Phase II	Phase III
COD	610	427	60	No significant improvement
BOD	290	203	20.3	No significant improvement
SS	280	84	67	No significant improvement
TN*	55	No significant improvement	No significant improvement	<6
TP**	13	No significant improvement	No significant improvement	<1.5

Source: Wuxi Drainage Company. The level of pollutants is those in the input and output water of the treatment plant. * TN represents Total Nitrogen. ** TP represents Total Phosphorus.

Costs of the Wastewater Treatment Project

The main function of the primary treatment (Phase I) is to prepare for the next treatment process. After the primary treatment, COD, BOD, and SS will be reduced by 30-70 percent, but the water cannot meet the GB standards.

The secondary treatment is mainly biological treatment. About 90 percent of COD, BOD, and SS are removed after secondary treatment. But secondary treatment cannot solve the problem of eutrophication, hence, most of the nitrogen (N) and phosphorus (P) remain in the treated water.

Phase III of the process is the deep treatment, using physico-chemical measures to remove N, P, and other pollutants. The deep treatment is extremely expensive compared with the two phase-treatments.

[7] Lower reaches of Lucun.

Table 3.8. Summary of capital costs, Phase I, $ million, 1992 price.

	Sewerage		Treatment works	
Capital costs	Financial costs	Economic costs	Financial costs	Economic costs
Land acquisition	0.27	0.27	0.55	0.55
Retic. Sewers	4.08	4.28	-	-
Pumping stations	0.47	0.49	-	-
Trunk sewers	-	-	-	-
Treatment works	-	-	4.72	5.10
Equipment	0.12	0.12	2.80	2.80
Tech. Assistance	0.01	0.01	0.12	0.12
Total	4.95	5.17	8.19	8.57

Table 3.9. Summary of capital costs, Phase II, $ million, 1992 price.

	Sewerage		Treatment works	
Capital costs	Financial costs	Economic costs	Financial costs	Economic costs
Land acquisition	0.24	0.24	0.31	0.31
Retic. Sewers	8.57	9.00	-	-
Pumping stations	1.34	1.41	-	-
Trunk sewers	5.69	5.97	-	-
Treatment works	-	-	9.87	10.66
Equipment	0.70	0.70	-	-
Tech. Assistance	0.46	0.46	0.35	0.35
Total	17.04	17.78	10.53	11.32

Table 3.10 Summary of capital costs, Phase III, $ million, 1992 price.

	Sewerage		Treatment works	
Capital costs	Financial costs	Economic costs	Financial costs	Economic costs
Total	3.0	3.12	30.12	32.53

To convert the financial costs to economic costs, the conversion factors for labor, plant, and equipment and materials provided by the World Bank were used.

Table 3.11. Annual operating costs, Lucun Treatment Plant, $ million, 1992 price.

Item	**I**	**II**	**III**
1. Electricity Water Coal	0.36 0.01 0	0.54 0.01 0.04	
2. Chlorine Polymer	0.01 0.01	0.04 0.01	
3. Wages	0.12	0.18	
4. Repair	0.09	0.16	
5. Other	0.05	0.10	
Total annual operating costs, Financial costs	0.65	1.08	
Total annual operating costs, Economic costs	0.86	1.43	3.16

3.3 Calculation of Wastewater Collection, Disposal, and Treatment Costs

The economic costs of these technological options (phases of the project) were estimated using the AIC (Average Incremental Cost) approach. The total incremental cost of wastewater collection, disposal, and treatment involved the following:

1. Investment costs, including present value of the average investment cost of the incremental sewer network systems and present value of the average investment cost of the incremental wastewater treatment plants.

2. Operating costs, including the present value of the average operating cost of the incremental sewerage system and present value of the average operating cost of the incremental wastewater treatment plant.

The AIC for wastewater disposal was estimated by dividing the discounted incremental costs by the corresponding discounted volume of incremental wastewater collected and treated by the project, as follows:

$$AIC = \frac{\sum \frac{I_t + R_t - R_0}{(1+i)^t}}{\sum \frac{Q_t - Q_0}{(1+i)^t}}$$

where I_t is the investment cost in year t, 0 represents the base year, R_t-R_0 is the extra operating cost in year t due to incremental wastewater disposal and treatment, Q_t-Q_0 is the incremental volume of wastewater disposed, and i represents the interest rate.

The calculations showed that at a discount rate of 10% the AIC for phase I was 0.132; phase II, 0.233; and phase III, 0.221. Base year was 1986, while 1992 price (in US dollars) was used. The AIC for each phase was the additional cost for that phase of the project.

The details of the calculation are presented in the Appendix (Tables A1, A2 and A3) section.

By combining the pollutant levels with each treatment level (Table 3.7) and the AIC with each treatment level, the AIC by types of pollutants was obtained (Tables 3.12 and 3.13, Figures 3.2 and 3.3).

Table 3.12. Estimated AIC by COD level.

COD, mg/l	610	427	60	60
AIC, $, 1992 price*	0	0.044	0.122	0.122

The AICs of Phases I and II were evenly shared for the removal of COD, BOD, and SS.

Table 3.13. Estimated AIC by TN level.

TN, mg/l	55	No significant improvement	No significant improvement	<6
AIC, $, 1992 price	0	0	0	0.111

The AIC of Phase III was evenly shared for the removal of TN and TP.

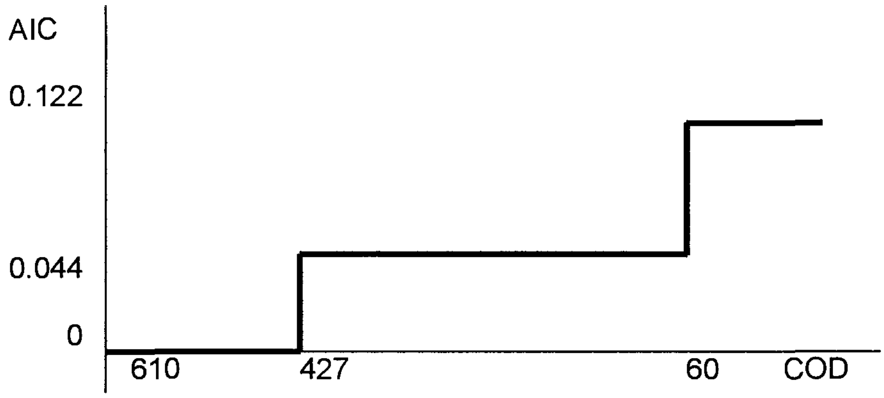

Figure 3.2. Estimated AIC by COD level.

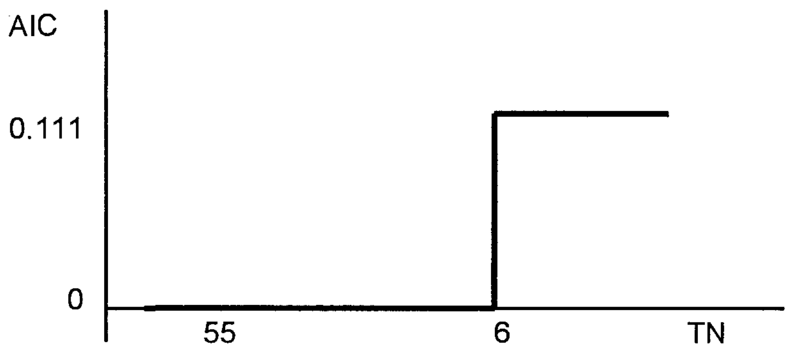

Figure 3.3. Estimated AIC by TN level.

Similar curves can be drawn for BOD, SS, and TP.

The AIC curve for all pollutant treatments can be drawn by adding the AIC curves for each pollutant, using total treatment level (if a common measurement for different pollutants can be found, e.g., percentage) as horizontal line.

4.0 BENEFITS OF THE WASTEWATER TREATMENT PROGRAM

The wastewater collection and treatment program carried out since 1987 in Wuxi has productivity, health, and amenity benefits. Productivity benefits include savings to the Wuxi Water Supply Company, Wuxi Drainage Company, industry users of water, and fish farmers. Health benefits include benefits to residents living near the Wuxi river system. Amenity benefits, on the other hand, include benefits to swimmers, tourists, and residents living adjacent to the canals.

This research focused on the benefits to the Water Supply Company and industry users, although the other benefits are also briefly discussed. The Wuxi river system, especially Lake Tai, is the source of potable water of the city. The serious pollution of the river system and Lake Tai would raise the cost of potable water treatment. A wastewater collection and treatment program will reduce the cost of potable water treatment, which is one of the main benefits of the program. Hence, wastewater disposal and treatment and potable water supply become stages in a continuous circle aimed at ensuring the city's water supply. The costs and benefits of each stage affect those of other stages. Figure 4.1 shows the relationship of wastewater disposal and potable water supply in the three stages.

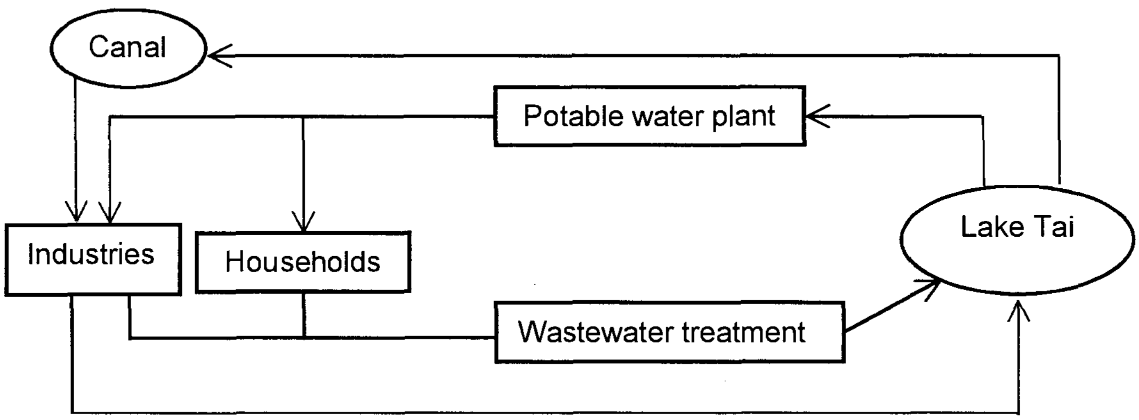

Figure 4.1. Relationship of wastewater disposal and potable water supply.

4.1 Savings to the Potable Water Supply

The Wuxi Water Supply Company supplied 260 million tonnes of potable water to industries and households in 1996. Most of the water came from Lake Tai. The average processing cost was 351 yuan per 1,000 tonnes.

The quality of water in the potable water supply has worsened in recent years. Table 4.1 shows the quality of source water at Zhongqiao Water Plant, the major water plant in the city supplying 60 percent of potable water.

Table 4.1. Source water quality at Zhongqiao Water Plant, 1994-1996.

	N-T mg/l	Oxygen consumed mg/l	Algae unit/l	Water quality evaluation, days of serious pollution per year
1994	1.26	4.63	578	39
1995	1.56	4.8	996	73
1996	2.29	5.34	5680	108

The pollution of water source has resulted in the increase of processing costs of the water plant. Table 4.2 shows the chemicals and electricity used in water treatment.

Table 4.2. Chemicals and electricity used in potable water treatment, Zhongqiao Plant.

	Cl kg/k tonne	Vitriol kg/k tonne	Electricity kWh/k tonne
1994	6.22	31.43	325.16
1996	6.27	35.82	312.01

Source: Wuxi Water Company.

Because of higher pollution in the source water, the water plants also used more water to wash their plants, filters, and tanks.

The combined effects of high pollution of the source water and the rising inflation, the average processing cost of the water plants in the recent years have increased (Table 4.3).

Table 4.3. Average processing cost of all potable water plants in Wuxi, 1993-1996

Year	Average processing cost (yuan/k tonne)
1993	265.384
1994	251.632
1995	315.771
1996	351.521

The Wuxi Water Company had estimated that with the wastewater treatment program, the processing costs would be reduced by five percent. The study assumed that the program will reduce processing cost by 4-6 percent. Water supply was estimated to increase by 3-5 percent annually until 2005. The estimated average processing cost was $0.03 per cubic meter (1992 price).

4.2 Savings to Industry

Industry uses 140 million tonnes of potable water and 60 million tonnes of canal water annually. It treats 40 percent of all water taken at a cost ranging from $0.035 to $0.09 per tonne. Improved canal water quality will reduce these treatment costs and enable some factories to switch from potable to canal water. The quantity of water used by industry was estimated to increase by 3.5-4.5 percent annually until 2005.

Industry is expected to save $0.0125-0.0175 per tonne on treatment cost for one-fifth of its water intake due to improved water quality in Lake Tai. Factories are also expected to save $0.0225-0.0275 per tonne on wastewater treatment costs for one-tenth of their treated wastewater. The quantity of wastewater was estimated to be 0.9 of water intake.

4.3 Other Benefits

Other benefits that can be generated through the wastewater treatment program include savings to the drainage company, savings to fisheries, agriculture benefits, public health benefits, residents' amenity benefits, residents' recreation benefits, tourists' benefits (Table 4.4).

Table 4.4. Other benefits generated through the wastewater treatment program.

Item	Benefit
Savings to the Wuxi Drainage Company	Renovation works on existing sewers of $9 million will be required without wastewater program. Sewerage project will save the company $4.5 million between 2000 and 2010.
Savings to fisheries	Increased output of 10,000 tonnes by 2.5-3.5%, ex-farm price of $1,200 per tonne. Annual increase in rate of output would be 3%.
Agricultural benefits	Not included
Public health benefits	About 2% (400,000 people) of the population living near the waterways suffer from a water-related stomach disorder for 2 days a year and one in 40 of these is hospitalized for an average of three days. The average value of lost output in rural areas is $2 per day and the hospital cost is $20 per day. Each of the 250,000 families in Wuxi spends $4-6 annually to prevent water-related diseases. The improvement of water quality will reduce these costs by 50% and 25%, respectively. The government spends $80,000 per year on programs to obviate disease caused by breeding of mosquitoes, and $40,000 annually for disease protection of the residents living along the rivers. Likewise, the improvement of water quality will reduce these costs by 25% and 35%, respectively.
Residents' amenity benefits	Ten percent of the 100,000 households in the affected area will experience an amenity benefit valued at 5% of the rent per person. The rent was assumed to be $1,100-900 annually per family. Average family size is 4 persons per family. Population annually increases by 2%.
Residents' recreation benefits	One-tenth of the local population was assumed to have recreation activities in the canals 16 times annually due to improved water quality and to be willing to pay $0.15 per swim.
Tourists' benefits	Wuxi attracts 190,000 foreign tourists and 1.25 million domestic visitors annually. These numbers increase by 3% every year. Foreign tourists were assumed to be willing to pay an average of $1 and domestic tourists $0.2 for the improvements.

4.4 Estimates of Total Benefits and Total Costs

Based on the above information, the total benefits and total costs for phase II of the wastewater treatment program were evaluated. The results are shown in Table 4.5. The cost-benefit analysis showed positive net benefits, although the value of the net benefits was not very large. The estimated average present value of the net benefits was $0.476 million, with a 10 percent discount rate. The net benefits are broadly-based as follows: industry savings, tourist benefits, amenity benefits, fishery benefits, water plant savings, each of which accounted for more than 10 percent of the total benefits.

Table 4.5 The results of cost-benefit analysis for wastewater program II in million Dollars.

	PV of total investment cost	PV of total extra operating cost	PV of savings to potable water treatment	PV of savings to industry	PV of savings to drainage company	PV of fishery benefits	PV of health benefits	PV of amenity benefits for residents	PV of recreation benefits	PV of tourist benefits	PV of total savings	PV of net savings
Low	22.062	3.367	2.077	6.150	1.404	2.385	2.146	3.241	1.728	3.726	22.858	-2.572
Average	22.062	3.367	2.705	7.283	1.404	2.862	2.596	3.601	1.728	3.726	25.905	0.476
High	22.062	3.367	3.383	8.460	1.404	3.339	3.046	3.961	1.728	3.726	29.048	3.619

Note: Discount rate = 0.10, base year = 1992, 1992 price, cash flow calculated for 20 years. PV = present value.

The net benefits ranged from -2.572 to 3.619 million US Dollars. The main factors affecting the variation of net benefits included: (1) annual increase in rate of potable water supply (3-5%) and reduction in processing cost (4-6%); (2) increase in rate of water intake by industries (3.5-4.5%), reduction in treatment cost for water intake by industries ($0.0125-0.0175/m^3), and reduction in wastewater treatment cost by industries ($0.0275-0.0225/m^3); (3) annual rent expenditure per family ($1100-900); (4) fishery output increase due to water improvement (2.5-3.5%); (5) family expense for protection against water-related diseases ($4-6). The lower estimates used the lower boundary of the above assumptions, while the higher estimates used the higher boundary. The results were quite sensitive to reductions in potable water treatment cost and treatment cost of industries.

To sum up, the wastewater collection and treatment program has some positive net benefits, but the result was sensitive to the assumptions of some key factors. Caution should be exercised when using these predictions for net benefits.

5.0 WATER PRICE AND POLICY IMPLICATION

Most of the benefits from wastewater treatment accrue to the users involved in water treatment and users of the water resources. Most household users of potable water benefit from wastewater treatment. Likewise, most industrial water users, except the big factories equipped with wastewater treatment equipment, also benefit from a central wastewater treatment. But currently, in most cities in China, only industrial users pay for use of the treatment system. Household users do not pay for use of the treatment systems. Hence, user charge to household users should be implemented.

5.1 Current Administrative and Pricing System in China

Investment in Wastewater Treatment System

In 1994, the length of the wastewater pipeline in China was 83,647 km. There were 139 wastewater treatment plants, including 84 secondary treatment plants. The total treatment capacity was 5,400,000 m^3 per day in 1994. In spite of the rapid development of the urban wastewater treatment system, the total capacity of wastewater treatment has remained inadequate. In 1996, only 60 percent of the urban area was serviced by wastewater collection pipelines, and less than 7 percent of the wastewater was centrally treated (Environmental Engineering Department, Tsinghua University, 1996).

The central wastewater disposal, collection, and treatment system is part of the urban infrastructure. Before the late 1970s, investments for the program came solely from the government, which were insufficient. Since the reform of the economic system starting in the late 1970s, investments in the wastewater treatment system have come from multiple sources, including: (1) central government investment, whose portion in the total investment has been decreasing; (2) local government investment, which comes from local taxes and charges, including wastewater disposal and treatment charges, part of water pollution charges, and water resource fee; (3) funds raised by beneficiaries; (4) foreign loans; and (5) domestic bank loans. In 1994, the total urban infrastructure investment and operating funds reached Y62.7 billion, of which Y8.1 billion came from central and local government special purpose investment, Y15.7 billion came from local taxes, Y32 billion came from local charges, and Y6.9 billion came from foreign and domestic bank loans. Within the urban infrastructure investment, only Y1.3 billion (2.1%) was for wastewater treatment (Environmental Engineering Department, Tsinghua University, 1996).

Fund insufficiency not only affected the investment in new treatment plants, but also the daily operations of existing plants. Because of lack of funds and other reasons, only 68 percent of the existing treatment capacity was used in 1994 (Environmental Engineering Department, Tsinghua University, 1996). Therefore, the financing problem for the wastewater treatment program is an urgent issue in China.

System of Wastewater Charges

Two agencies, the Environmental Protection Administration and Municipal Utility Administration, manage the water supply and wastewater disposal in China.

The wastewater disposal charge system for industrial users was implemented in 1982 and revised in 1991. In this system, the wastewater disposed (mainly industrial wastewater) that exceeds the standard is charged a pollution fee (Table 5.1). At the same time, the Municipal Utility Administration charges the business users for using the wastewater collection and treatment system. Households were included in the charity scheme in the mid-1990s only.

Calculations were as follows:

Total charge = unit charge * total amount of pollutant over the standard disposed (times/tonne water)

Amount of pollutant over the standard disposed (times/tonne water) = wastewater disposed (tonne) * times pollutant in water over standard (times)

Total charge for class B = fixed charge + unit charge * total over standard pollutant disposed (times/tonne water)

The main problem of the charge system in China is that the unit charge is too small to force the polluter to reduce wastewater disposal. Therefore, the unit charge needs to be raised.

Another recommended policy is charging households a wastewater disposal fee. The fee can be added to the tap water price. Some of the cities, including Wuxi, have begun doing this recently.

Table 5.1. Charges for disposed wastewater exceeding the standard.

Pollutant	Above standard pollutant disposed (times/tonne water)	Unit charges Class A[8] (Y)	Unit charges Class B (Y)	Fixed Charges for class B (Y)
Mercury	2,000	2.00	1.00	2,000
Cadmium (Cd)	3,000	1.00	0.15	2,550
Benzo (a) pyrene	3,000,000	0.06	0.03	90,000
Chrome	150,000	0.06	0.03	4,500
Arsine	150,000	0.09	0.02	10,500
Lead	150,000	0.08	0.03	7,500
Nickel	150,000	0.08	0.03	7,500
PH	5,000	0.25	0.05	1,000
Color	100,000	0.14	0.04	10,000
Suspended substance	800,000	0.03	0.01	16,000
BOD	30,000	0.18	0.05	3,900
COD	20,000	0.18	0.05	2,600
Petroleum, oil	25,000	0.20	0.06	3,500
Volatile phenol	250,000	0.06	0.03	7,500
Cyanide	250,000	0.07	0.04	7,500
Sulfide	250,000	0.05	0.02	7,500
Ammonia nitrogen	25,000	0.10	0.03	1,750
Fluoride	25,000	0.30	0.09	5,250
Phosphate	250,000	0.05	0.02	7,500
Formaldehyde	200,000	0.12	0.06	12,000
Aniline	200,000	0.12	0.06	12,000
Nitrobenzene	200,000	0.10	0.04	12,000
Synthetic detergent	25,000	0.30	0.09	5,250
Copper	250,000	0.04	0.02	5,000
Zinc	100,000	0.06	0.02	4,000
Manganese	100,000	0.06	0.02	4,000
Organic pesticide	250,000	0.07	0.04	7,500

Source: National Environmental Protection Bureau, 1996.

5.2 Recommendations of the Watson Hawksley (WH) Report

The WH report mainly provided technical recommendations. It analyzed the costs and benefits of different wastewater disposal plants and recommended that all wastewater from Wuxi be treated before disposal. It did not recommend disposing wastewater to Yangtse River for technical and economic reasons. The administration accepted its recommendations and decided to implement project 1 (Table 3.4), which meant treating wastewater in Wuxi and disposing it to Lake Tai.

The other technical recommendations included:

- Continuously building the wastewater collection network and treatment plant in Lucun area.

[8] Class A is used when the quantity of wastewater disposed is less or equal to the boundary quantity. Class B is used otherwise.

- Implementing the secondary degree treatment in Lucun treatment plant.
- Connecting the wastewater disposal network of the small factories in Lucun area to the central wastewater collection network.
- Increasing the treatment capacity of the big factories and allowing them to discharge wastewater directly into the rivers around Wuxi.

The WH report calculated the total investment cost, and made some suggestions on how to raise the required fund. Three possible fund sources were identified in the report: user charges, loans, and municipal government financing. The report recommended that the user charge should be based on the actual cost of wastewater collection and treatment. However in the current regulations, the user charge includes network connection fee (determined by the investment cost of wastewater collection network and treatment plant) and treatment fee (determined by the volume of water and the treatment cost), which does not cover the whole cost. Moreover, the user charge did not include household users until recently. The loans from the World Bank cover about 50 percent of the investment cost. Since the user charge and World Bank's loan combined cannot cover all costs, the municipal government finance has to meet the deficit. The municipal government's fund comes from wastewater disposal fee and innovation fund.

The WH report also discussed the source and use of fund of the different investment options. It found that under the current user charge system, the wastewater collection and treatment company could not be financially independent. The municipal government's financial support will be needed even for the earlier project (before 2000). The later project (after 2000) will need more funds, and will still rely on the municipal government's financial support if the needed amount could not be raised from user charges.

The report discussed another user charge system, which covers all investment and operating costs of the project and enables the company to be financially independent.

5.3 Actions Taken to Implement the WH Recommendations

The technical recommendations of the WH report were largely accepted by the Wuxi municipal government. These included the treatment of wastewater in Lucun treatment plant and disposal to Lake Tai; construction of phase I and II of Lucun treatment plant has been completed in 1997.

The Wuxi municipal government financially supported the project until 1997 when the user charge system was changed, following some WH report recommendations. The household potable water price was increased from 0.60 yuan per tonne to 0.75 yuan per tonne starting March 1, 1997. The new price includes the wastewater treatment cost of 0.10 yuan, which still cannot cover the total cost of wastewater treatment but is a good starting point.

For industry water users, a fixed wastewater treatment fee has been added to the potable water price in Wuxi since March 1997. However, since the amount of potable water used does not match the amount of wastewater discharged by the industry water users, using a metering system would be better than adding a wastewater fee to the potable water price.

Table 5.2. Potable water price components in Wuxi, yuan per tonne.

	Base Price	Water plant construction fee	City surcharge	Water resource fee	Irrigation works fee	Wastewater treatment fee	Total
Before Mar.1997							
Household	0.41	0.15	0.04	-	-	-	0.60
Industry	0.70	0.20	0.04	0.01	-	-	0.95
After Mar. 1997							
Household	0.435	0.15	0.04	0.01	0.015	0.10	0.75
Industry	0.71	0.20	0.04	0.01	0.04	0.10	1.10

5.4 Calculation of the Full Cost of Water

The main policy implication of this project is that wastewater disposal and treatment are not free. Without a wastewater disposal and treatment system, the environment will be polluted and social costs will be incurred. To avoid environmental damage, wastewater should be treated and this cost should be paid by people and companies that discharge wastewater into the environment. Since it is not technically feasible to collect pollution charges from each household, wastewater collection and treatment costs are usually added to the potable water price.

This paper added AIC of wastewater disposal to the AIC of potable water to get the full cost of water price in Wuxi. The cost of the first phase (1998-2003) of the investment of Gong Hu Water Plant (a new major plant that takes in water from outer Lake Tai) was used. The discount rate was assumed to be 10 percent. The investment and operating costs of the third phase of the central treatment system were also calculated. The new water plant was assumed to be in operation for 50 years. Table 5.3 shows the estimates, where PVinv stands for present value of investment, PVQ stands for discounted water quantity, PVopc stands for present value of the change in operating cost, PVWc represents the present value of water input cost, PVinvenv represents present value of the central wastewater treatment system investment cost, and PVopcenv represents present value of the change in wastewater treatment operating cost. Water price was estimated at 0.97 yuan per tonne using 1992 price. This was translated into 1997 price using a price index of 200 percent.

Table 5.3. Estimated water price in 2004, base year 1998, r = 0.10, in 1992 yuan per tonne.

PVinv/PVQ	PVopc/PVQ	Pvinvenv/PVQ	PVopcenv/PVQ
0.255843	0.300055	0.328986	0.088236
Sum	sum in 1997 price		
0.97312	1.94624		

It is practicable for the municipal government to include the wastewater discharge fee into the water price. In fact, the Wuxi municipal government has already changed the water price recently.

All households in Wuxi are connected to sewers. Therefore, while the problem of how to charge households not connected to the sewers does not exist in Wuxi, it could be a problem for other cities if a wastewater disposal fee is added to the potable water price.

By comparing Table 5.3 with 5.2, it is observed that the actual water price (1997 level) is much lower than the full price estimate of this project.

5.5 Proposed Wastewater Disposal Charge System

Figure 5.1 presents the wastewater disposal charge system proposed by this project.

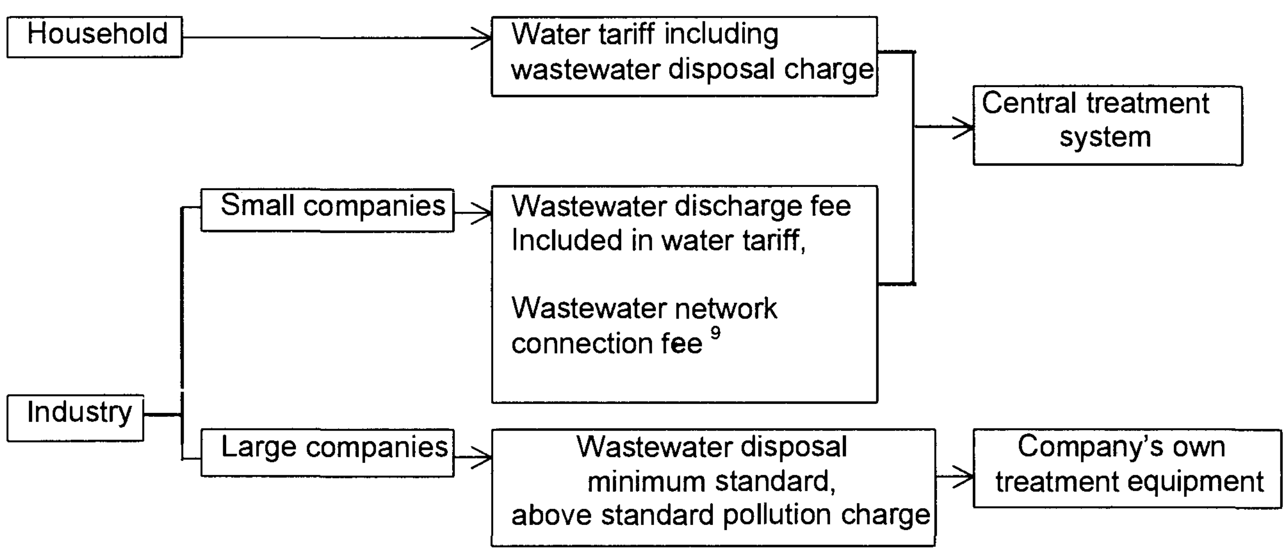

Figure 5.1. A wastewater disposal charge system.

Households. A wastewater disposal charge is added to the potable water price. Each household is connected to the central treatment network.

Small companies. Small companies pay a wastewater treatment fee included in the water tariff for industries. They are connected to the central treatment network, pay a network connection fee.

Large companies. Large companies use their own treatment equipment. If the disposed wastewater does not meet the standard, the companies have to pay a pollution charge. A metering system should be implemented to measure the quality of wastewater disposed by each company.

[9] Small industries will be subject to some control, e.g., random inspections.

The whole system could be implemented gradually following a schedule. For technical reasons, the large companies' potable water price could also include a minimum wastewater treatment cost. A phased schedule of proposed tariffs and levels of pollution charges by class of water user are shown in Table 5.4. The water tariffs for both households and companies will reach the full economic price in 2010, with the company's tariff increasing faster than the households'. The small companies will pay also a network connection fee. The large companies' pollution charge will gradually increase to a level close to the wastewater treatment charge paid by households and small companies.

Table 5.4. A phased schedule of proposed tariffs and levels of pollution charges, 1997 yuan.

	Item	1997	1998	2004	2010
Households	Water tariffs (per tonne water)	0.75	0.95	1.25	1.94
	Wastewater treatment fee included in water tariffs (per tonne water)	0.10	0.25 Covering all operating costs and a small part of production cost.	0.50	0.84 Covering all production and operating costs of water and wastewater.
Small companies	Wastewater treatment fee included in water tariffs (per tonne water)	0.10	0.30	0.60	0.84
	Network connection fee (per tonne wastewater)	0.10	0.14	0.17	0.20
Large companies	Average pollution charge in excess of standard (per tonne wastewater)	<0.05	0.25	0.50	0.71*

* In 2010, the pollution charge for large plant would approach the treatment cost of the central treatment plant. The social cost of wastewater disposal by a large plant may be larger than that amount. The wastewater treatment fee per tonne of water has been converted to pollution charge per tonne of wastewater by a collection rate of 0.85.

The water prices and wastewater treatment fees in Table 5.4 were based on the water price estimates given in Table 6.3. The water price for households in 2010 (Table 5.4) is 1.94 yuan, which is exactly the full economic price estimated in this paper (Table 5.3). This price includes a wastewater treatment fee of 0.84 yuan (Table 5.4), which is the sum of unit wastewater treatment investment cost (PVinvenv/PVQ) and unit wastewater treatment operating cost (PVopcenv/PVQ) times the price index (converting 1992 price into 1997 level). The treatment fee for small companies is 0.84 yuan. The average pollution charge in excess of standard for large companies (0.71 yuan) is 0.84 yuan times a collection rate of 0.85, because the pollution charge is calculated in terms of wastewater.

A unitary agent of the municipal government should be in charge of the collection of potable water fee, network connection fee, and pollution charge.

Meanwhile, the Chinese State Planning Committee is designing a water charge system that will include water fee and a wastewater discharge fee. The system is quite likely to be put into practice in the near future in China. The findings and recommendations of this study will serve as guidelines to the government in setting up the price for wastewater disposal.

6.0 CONCLUSION

The major findings of this project are as follows:

1. The marginal cost of wastewater disposal, collection, and treatment was calculated using the Average Incremental Cost (AIC) approach. AIC curves were developed showing the relationship between the effort to remove certain pollutants and the costs of doing so. The estimated water price and wastewater charges were much greater than the current water price and wastewater charges.

2. A cost and benefit analysis was carried out which included costs and benefits to industries, fish farmers, and urban households. The analysis showed that the treatment program has positive net benefits, but the result was sensitive to the assumptions of some key factors.

3. The current water tariff and wastewater charge system was reviewed and the full economic cost of water was calculated. The estimated tariff was much higher than the current tariff.

The major policy recommendations of this project are as follows:

- Raise the water price and wastewater charges in Wuxi gradually within 10 years to a level that would cover the full economic cost.

- Design a wastewater collection and treatment charge system in which households, small factories, and large factories are treated differently. A phased schedule of proposed tariffs and levels of pollution charges were presented, showing a gradual change in price in the process of the pricing reform. The full economic price of water will be reached in 2010.

REFERENCES

Dixon, J.A., L.F. Scura, R.A. Carpenter, and P.B. Sherman. 1994. Economic Analysis of Environmental Impacts. Earthscan Publications Ltd. London

Environmental Engineering Department, Tsing Hua University.1996. Study on Charging Method and Standard for Urban Domestic Sewage.

Freeman, A.M. III. 1979. The Benefits of Environmental Improvement: Theory and Practice. Johns Hopkins University Press. Baltimore.

Krupnick, A.J. and P.R. Portney. 1991. Controlling Urban Air Pollution: A Benefit-Cost Assessment. Science. 252. pp. 522-528.

Lave, L.B. and E.P. Seskin. 1977. Air Pollution and Human Health. Johns Hopkins University Press for Resources for the Future. Baltimore.

National Environmental Protection Bureau. 1996. Waste Disposal Charge System. China Environmental Science Press.

National Science and Technology Committee of PRC. 1992. The Final 1992 Research Report on the Reform of Water Pricing in Beijing. National Science and Technology Committee. Beijing, PRC.

Rosen, S. 1974. Hedonic Prices and Implicit Markets: Product Differentiation in Perfect Competition. Journal of Political Economy. 82:1. pp. 34-55.

State Statistical Bureau. 1996. China Statistical Yearbook 1996. China Statistical Publishing House, Beijing.

Statistical Bureau of Wuxi. 1997. Statistical Yearbook of Wuxi 1997. China.

Hawksley, Watson. 1992. Wuxi Wastewater Treatment Overall Plan. Unpublished Report.

Warford J. 1994. Marginal Opportunity Cost Pricing for Municipal Water Supply. EEPSEA discussion paper, August 1994.

Warford J., S. Hansen, T. Panayotou, and W. Spofford. 1994. Marginal Opportunity Cost Pricing: Water, Coal and Forest Resources in China.

Wu, Yangshang (ed.). 1992. Urban Wastewater Treatment. China Environmental Science Press. China.

Wuxi Environmental Protection Bureau. 1995. Waste Disposal in Wuxi City. China.

Zhang F., R. Lubis, A. Dehlavi. 1995. Water Pricing: A Case Study of Beijing. (A proposal submitted to HIID International Environmental program). Unpublished Report.

APPENDICES

Appendix Table A1. Calculation of AIC, Program Phase I (million dollars 1992 price and quantity of water in million tonnes).

Year	#	Inv C	Q	PV Inv C	PV Q	Chg opC	PV chg op C
1987	1	2.29		2.081818			
1988	2	2.29		1.892562			
1989	3	2.29		1.720511			
1990	4	2.29		1.564101			
1991	5	2.29		1.421910			
1992	6	2.29	18.25	1.292645	11.33181	0.86	0.533992
1993	7		18.25		10.30165	0.86	0.485448
1994	8		18.25		9.365136	0.86	0.441316
1995	9		18.25		8.51376	0.86	0.401196
1996	10		18.25		7.739782	0.86	0.364724
1997	11		18.25		7.036165	0.86	0.331567
1998	12		18.25		6.396514	0.86	0.301425
1999	13		18.25		5.815012	0.86	0.274023
2000	14		18.25		5.286375	0.86	0.249111
2001	15		18.25		4.805795	0.86	0.226465
2002	16		18.25		4.368905	0.86	0.205877
2003	17		18.25		3.971732	0.86	0.187161
2004	18		18.25		3.610665	0.86	0.170146
2005	19		18.25		3.282423	0.86	0.154679
2006	20		18.25		2.984021	0.86	0.140617
2007	21		18.25		2.712746	0.86	0.127834
2008	22		18.25		2.466133	0.86	0.116212
2009	23		18.25		2.241939	0.86	0.105648
2010	24		18.25		2.038126	0.86	0.096043
2011	25		18.25		1.852842	0.86	0.087312
2012	26		18.25		1.684402	0.86	0.079375
2013	27		18.25		1.531275	0.86	0.072159
2014	28		18.25		1.392068	0.86	0.065599
2015	29		18.25		1.265516	0.86	0.059635
2016	30		18.25		1.150469	0.86	0.054214
2017	31		18.25		1.045881	0.86	0.049285
2018	32		18.25		0.950801	0.86	0.044805
2019	33		18.25		0.864365	0.86	0.040732
2020	34		18.25		0.785786	0.86	0.037029
	35		18.25		0.714351	0.86	0.033663
Sum				9.973547	117.5064		5.53729
Int. R=0.10						AIC	0.13200

Appendix Table A2. Calculation of AIC, Program Phase II (million dollars 1992 price and quantity of water in million tonnes).

Year	#	Inv C	Q	PV Inv C	PV Q	Chg opC	PV chg op C
1987	1			0			
1988	2			0			
1989	3			0			
1990	4			0			
1991	5			0			
1992	6			0	0		0
1993	7	5.82		3.285238	0		0
1994	8	5.82		2.986580	0		0
1995	9	5.82		2.715073	0		0
1996	10	5.82		2.468248	0		0
1997	11	5.82	18.25	2.243862	7.036165	0.57	0.321750
1998	12		18.25		6.396514	0.57	0.292500
1999	13		18.25		5.815012	0.57	0.265909
2000	14		18.25		5.286375	0.57	0.241736
2001	15		18.25		4.805795	0.57	0.219760
2002	16		18.25		4.368905	0.57	0.199782
2003	17		18.25		3.971732	0.57	0.181620
2004	18		18.25		3.610665	0.57	0.165109
2005	19		18.25		3.282423	0.57	0.150099
2006	20		18.25		2.984021	0.57	0.136453
2007	21		18.25		2.712746	0.57	0.124049
2008	22		18.25		2.466133	0.57	0.112771
2009	23		18.25		2.241939	0.57	0.102520
2010	24		18.25		2.038126	0.57	0.093200
2011	25		18.25		1.852842	0.57	0.084727
2012	26		18.25		1.684402	0.57	0.077024
2013	27		18.25		1.531275	0.57	0.070022
2014	28		18.25		1.392068	0.57	0.063657
2015	29		18.25		1.265516	0.57	0.057870
2016	30		18.25		1.150469	0.57	0.052609
2017	31		18.25		1.045881	0.57	0.047826
2018	32		18.25		0.950801	0.57	0.043478
2019	33		18.25		0.864365	0.57	0.039526
2020	34		18.25		0.785786	0.57	0.035932
2021	35		18.25		0.714351	0.57	0.032666
2022	36		18.25		0.649410	0.57	0.029696
2023	37		18.25		0.590373	0.57	0.026997
2024	38		18.25		0.536702	0.57	0.024542
2025	39		18.25		0.487911	0.57	0.022311
2026	40		18.25		0.443556	0.57	0.020283
Sum				13.699	72.962260		3.336422
Int. R=0.10						AIC	0.233483

Appendix Table A3. Calculation of AIC, Program Phase III.

Year	#	Inv C	Q	PV Inv C	PV Q	Chg opC	PV chg op C
1987	1			0			
1988	2			0			
1989	3			0			
1990	4			0			
1991	5			0			
1992	6			0	0		0
1993	7			0	0		0
1994	8			0	0		0
1995	9			0	0		0
1996	10			0	0		0
1997	11			0	0		0
1998	12			0	0		0
1999	13			0	0		0
2000	14	3.57		1.034102	0		0
2001	15	3.57		0.940093	0		0
2002	16	3.57		0.854630	0		0
2003	17	3.57		0.776936	0		0
2004	18	3.57		0.706305	0		0
2005	19	3.57		0.642096	0		0
2006	20	3.57		0.583724	0		0
2007	21	3.57		0.530658	0		0
2008	22	3.57		0.482416	0		0
2009	23	3.57	36.5	0.438560	4.483878	1.73	0.311156
2010	24		36.5		4.076253	1.73	0.282869
2011	25		36.5		3.705684	1.73	0.257153
2012	26		36.5		3.368804	1.73	0.233776
2013	27		36.5		3.062549	1.73	0.212524
2014	28		36.5		2.784135	1.73	0.193203
2015	29		36.5		2.531032	1.73	0.175639
2016	30		36.5		2.300938	1.73	0.159672
2017	31		36.5		2.091762	1.73	0.145156
2018	32		36.5		1.901602	1.73	0.131960
2019	33		36.5		1.728729	1.73	0.119964
2020	34		36.5		1.571572	1.73	0.109058
2021	35		36.5		1.428702	1.73	0.099144
2022	36		36.5		1.298820	1.73	0.090131
2023	37		36.5		1.180745	1.73	0.081937
2024	38		36.5		1.073405	1.73	0.074488
2025	39		36.5		0.975823	1.73	0.067717
2026	40		36.5		0.887111	1.73	0.061560
2027	41		36.5		0.806465	1.73	0.055964
2028	42		36.5		0.733150	1.73	0.050876
2029	43		36.5		0.666500	1.73	0.046251
2030	44		36.5		0.605909	1.73	0.042047
2031	45		36.5		0.550826	1.73	0.038224
2032	46		36.5		0.500751	1.73	0.034749
2033	47		36.5		0.455228	1.73	0.031590
2034	48		36.5		0.413844	1.73	0.028718
2035	49		36.5		0.376222	1.73	0.026108
2036	50		36.5		0.342020	1.73	0.023734
2037	51		36.5		0.310927	1.73	0.021577
2038	52		36.5		0.282661	1.73	0.019615
Sum				6.989519	46.213390		3.206947
Int R= 0.10						AIC	0.220639

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